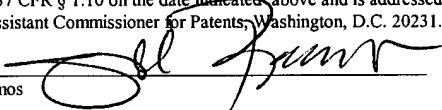


Express Mail" mailing label number EL 782718934 US

Date of Deposit: May 3, 2001

I hereby certify that this paper or fee is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" under 37 CFR § 1.10 on the date indicated above and is addressed to the Assistant Commissioner for Patents, Washington, D.C. 20231.

Jose Ramos



UNITED STATES PATENT APPLICATION

FOR

METHOD AND APPARATUS FOR INTERFERENCE

REDUCTION IN A POSITIONING SYSTEM

INVENTORS:

Todd V. Townsend
Sergey Lyusin

PREPARED BY:

Coudert Brothers
333 South Hope Street
Twenty - Third Floor
Los Angeles, CA 90071
(213) 229-2900

Applicant hereby claims priority to provisional patent application 60/201,625 filed May 3, 2000.

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

5

The present invention relates to locating the position of an object, and in particular embodiments of the present invention are directed toward using a satellite positioning system to locate the position of objects that are obstructed.

2. BACKGROUND ART

People use positioning systems to precisely determine the locations of objects. One type of positioning system is the Global Positioning System (GPS) and uses multiple satellites that orbit the earth. The satellites transmit signals to earth that can be detected by anyone with a receiver. Currently, however, it is impossible to track objects using the receiver when the object is obstructed, for instance within an enclosed structure such as a parking garage or building, or under a tree or bridge. Before further discussing the drawbacks associated with current positioning systems, it is instructive to discuss navigation generally.

Navigation

Since the beginning of recorded time, people have been trying to figure out a reliable way to determine their own position to help guide them to where they are going and to get them back

home again. On land people relied on maps, landmarks, and local residents to navigate. There are no landmarks or residents on the ocean, however, so sea travel was particularly difficult. To avoid getting lost, early sailors followed the coastline closely, rarely going out of sight of land. When humankind first sailed into the open ocean, they used the stars to chart their path. The north star was used in the northern hemisphere but was not available once a ship was too far south of the equator. The compass was also used to determine the direction of North but could only provide direction information, but not position information. Eventually clocks were developed that could be used at sea so that longitudinal (east west) directions could be determined.

Still, however, it was impossible to exactly where you were with any precision. In modern times, the need and desire to know the exact location on sea or land within meters arose. Military, commercial, and personal requirements created the need for more accurate positioning systems. In the early 20th century ground based radio navigation systems were developed. One drawback of using a ground based radio system is the tradeoff between coverage and accuracy. High-frequency radio waves provide accurate position location but can only be picked up in a small, localized area. Lower frequency radio waves cover a larger area, but cannot pinpoint the location of an object with precision.

Satellite Positioning System

To partially solve the problems associated with ground-based navigation systems, high-frequency radio transmitters were placed in space as part of the GPS system. As is well known,

GPS was established by the United States government, and employs a constellation of satellites in orbit around the earth at an altitude of approximately 26500 km. Currently, the GPS constellation consists of 24 satellites, arranged with 4 satellites in each of 6 orbital planes. Each orbital plane is inclined to the earth's equator by an angle of approximately 55 degrees.

5

Each GPS satellite transmits microwave L-band radio signals continuously in two frequency bands, centered at 1575.42 MHz and 1227.6 MHz., denoted as L1 and L2 respectively. The GPS L1 signal is quadri-phase modulated by a coarse/acquisition code ("C/A code") and a precision ranging code ("P-code"). The L2 signal is binary phase shift key ("BPSK") modulated by the P-code. The GPS C/A code is a gold code that is specific to each satellite, and has a symbol rate of 1.023 MHz. The unique content of each satellite's C/A code is used to identify the source of a received signal. The P-code is also specific to each satellite and has a symbol rate of 10.23 MHz. The GPS satellite transmission standards are set forth in detail by the Interface Control Document GPS (200), dated 1993, a revised version of a document first published in 1983.

Another satellite positioning system is called GLONASS. GLONASS was established by the former Soviet Union and operated by the Russian Space Forces. The GLONASS constellation consists of 24 satellites arranged with 8 satellites in each of 3 orbital planes. Each orbital plane is inclined to the earth's equator by an angle of approximately 64.8 degrees. The altitude of the GLONASS satellites is approximately 19100 km.

The satellites of the GLONASS radio navigation system transmit signals in the frequency band near 1602 MHz, and signals in a secondary band near 1246 MHz, denoted as L1 and L2 respectively. The GLONASS L1 signal is quadri-phase modulated by a C/A code and a P-code. The L2 signal is BPSK modulated by the P-code. Unlike GPS, in which all of the satellites transmit on the same nominal frequency, the GLONASS satellites each transmit at a unique frequency in order to differentiate between the satellites. The GLONASS L1 carrier frequency is equal to $1602 \text{ MHz} + k * 0.5625 \text{ MHz}$, where k is a number related to the satellite number. The GLONASS L2 carrier frequency is equal to $1246 \text{ MHz} + k * 0.5625 \text{ MHz}$. The GLONASS C/A code consists of a length 511 linear maximal sequence. Details of the GLONASS signals may be found in the Global Satellite Navigation System GLONASS--Interface Control Document of the RTCA Paper No. 518-91/SC159-317, approved by the Glavkosmos Institute of Space Device Engineering, the official former USSR GLONASS responsible organization.

In addition to transmitting high frequency signals, both satellite systems send navigation messages and ephemeris data. The navigation message is a low frequency signal that identifies the satellite and provides other information. The ephemeris data provides information on the path and position of the satellite.

Current Receivers

Conventional receivers, called GPS or SPS receivers, work well when the signals travel directly from the satellite to the receiver with no obstructions in the way. When passing under trees, bridges, through garages and when the receiver is in a building, however, problems occur.

Specifically, these objects present barriers that interfere with the signal and weaken it. Even worse, the navigation message, which is typically more difficult to detect than the signals, is often undetectable when there are obstructions.

5 Secondly, the receiver relies on detecting reflected signals. Obstructions between the signal sent by the satellite and the receiver compromise the signal path.. The signal reflects off nearby surfaces and then to the receiver. Some of these signals may be stronger than another, even though the distance the signal travels is further, depending on the reflecting surface or surfaces. This extra distance traveled by the signal can introduce errors into the distance and
10 location calculations.

 It is desirable to overcome this difficulty for a variety of reasons. First, it would be desirable to locate an object in a building in order to allow the users of positioning devices to obtain a fix and assess position-related data to access nearby services. Second, federal mandates
15 may require the ability to locate cell phone users to a high degree of accuracy (e.g. within 100 feet) so that 911 services can locate an emergency caller even when the cell phone is used in a building or obstructed area. It would be desirable to provide a SPS receiver to overcome the above problems.

SUMMARY OF THE INVENTION

Embodiments of the present invention relate to a method and apparatus for reducing interference in a positioning system. According to one or more embodiments of the present invention, the receiver in a conventional positioning system is configured to communicate with a terrestrial broadcast station. The terrestrial broadcast station transmits assistance signals to the receiver and enable the receiver to locate very weak signals being transmitted from the satellites in the positioning system.

In one embodiment, the assistance signals include Doppler frequencies for the satellites. In another embodiment, the assistance signals include Ephemeris data. In another embodiment, the assistance signals include almanac data. Almanac data is a list of satellites that a particular receiver should be able to access currently. This prevents the receiver from searching for satellites, for instance, that are below the horizon and not currently usable. In other embodiments of the present invention, the assistance signal includes navigation bits demodulated from the carrier phase inversion signal of the satellite, time synchronization signals, base station coordinates for 1 ms ambiguity resolution, and pseudo range differential corrections.

The assistance information may be provided by a wire, a computer network such as the Internet, or it may be provided wirelessly, such as via a cellular telephone network, wireless data network, a secondary carrier on a transmitter in the commercial broadcast service (TV or AM/FM radio) or by another equivalent means. The assistance signal permits the use of a coherent decoding and the provision of needed data which enables a receiver with a weak acquisition to

maintain a lock even when it does not have a strong enough signal acquisition to independently decode needed data. A conventional correlation path is used to provide ghost satellite cancellation. When a signal is detected in the conventional path, it is inverted and subtracted from the assisted correlation path.

LA 49853v1

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, aspects and advantages of the present invention will become better understood with regard to the following description, appended claims and accompanying
5 drawings where:

Figure 1 is a low signal-to-noise ratio positioning system according to an embodiment of the present invention.

10 Figure 2 shows the use of an assistance signal according to an embodiment of the present invention.

15 Figure 3 shows the use of an assistance signal according to another embodiment of the present invention.

Figure 4 shows the use of an assistance signal according to another embodiment of the present invention.

20 Figure 5 is a digital message from a satellite to a receiver according to an embodiment of the present invention.

Figure 6 shows the use of an assistance signal according to another embodiment of the present invention.

Figure 7 shows a positioning system architecture according to an embodiment of the present invention.

5 Figure 8 shows a positioning system according to an embodiment of the present invention.

FIG. 7 is a block diagram of a positioning system architecture according to an embodiment of the present invention. The system includes a host device 700, a positioning system 710, and a user device 720. The host device 700 is connected to the positioning system 710, which in turn is connected to the user device 720. The positioning system 710 includes a base station 711 and a mobile station 712. The base station 711 is connected to the host device 700 and the mobile station 712. The mobile station 712 is connected to the user device 720. The user device 720 includes a user interface 721 and a processing unit 722. The processing unit 722 is connected to the user interface 721 and the mobile station 712. The system is configured to provide positioning services to the user device 720.

DETAILED DESCRIPTION OF THE INVENTION

The invention relates to a method and apparatus for reducing interference in a positioning system. In the following description, numerous specific details are set forth to provide a more
5 thorough description of embodiments of the invention. It will be apparent, however, to one skilled in the art, that the invention may be practiced without these specific details. In other instances, well known features have not been described in detail so as not to obscure the invention.

Positioning System Using Assistance Signals

One embodiment of the present invention is shown in Figure 1. At step 100, signals are transmitted from multiple satellites to earth. Then, at step 110, a receiver located on earth receives some of the signals. Next, at step 120, assistance signals are transmitted from a
5 terrestrial broadcast station. Finally, position information is obtained at step 130 by using the satellite and assistance signals.

As shown at step 120 of Figure 1, assistance signals are sent from a terrestrial broadcast station to a receiver to assist the receiver in obtaining positioning information, specifically when
20 the receiver is indoors or when obstacles are in the way. The assistance signals may have various information in them according to various embodiments of the present invention. In one embodiment, the assistance signals have Doppler frequencies for the satellites.

Doppler Frequencies

The satellites themselves are traveling very fast in orbit around the earth. Therefore, it is inevitable that the signal sent by the satellite will be altered by the Doppler effect. In practical terms this means, for instance, that if all satellites are transmitting signals at 1575 megahertz then a receiver must locate and receive each of these signals at something other than 1575 megahertz, depending on the direction the satellite is currently traveling.

In one embodiment of the present invention, a terrestrial broadcast station in the general vicinity as a target receiver is chosen where the terrestrial broadcast station is in a more ideal position to receive and calculate accurate Doppler information. This might include, for instance, a broadcast station that has a more powerful antenna or is farther away from obstacles. The broadcast station should be sufficiently close (within 50 to 100 miles, for instance) so that its Doppler shifts are substantially the same as the target receiver and its signals are received from the same satellites. The terrestrial broadcast station, then, is able to locate the satellites and calculate their frequency variations based on the Doppler effect and transmit this information to the target receiver.

In practical terms, this means that a receiver that is obstructed does not have to search the spectrum to locate the correct frequencies for satellite signals varied by the Doppler effect. The assistance signal tells the receiver exactly what frequency to use. Then, the receiver is able to tune to exactly that frequency and no time is expended searching through frequency ranges to

lock in on Doppler affected satellite frequencies and the obstructed receiver may immediately begin to correlate the messages in the signal.

This embodiment of the present invention is shown in Figure 2. At step 200, signals are transmitted from multiple satellites to earth. Then, at step 210, a receiver located on earth receives some of the signals. Next, at step 220, a terrestrial broadcast station that is located sufficiently near to the target receiver calculates true Doppler frequencies for the satellites. Then, at step 230, the true Doppler frequencies are transmitted to the target receiver. Thereafter, the target receiver uses the true Doppler frequencies and tunes to those frequencies at step 240, and begins correlating at those frequencies at step 250.

Ephemeris Data

In one embodiment of the present invention, the assistance signals provide Ephemeris data. Ephemeris data is data that tells the target receiver exactly where each satellite is. Knowing the location of each satellite is essential to calculating the receiver's position. Take, for instance, the case where a receiver is located indoors. Even if the receiver was broadcast Doppler information from a terrestrial broadcast station, the receiver still might not be able to obtain a positional fix because the information telling it where the satellites are was too weak to reach it.

This embodiment of the present invention is shown in Figure 3. In Figure 3, signals are transmitted from multiple satellites to earth at step 300. Then, at step 310, a target receiver

located on earth receives some of the signals. Next, at step 320, a terrestrial broadcast station that is located sufficiently near to the target receiver calculates true Doppler frequencies for the satellites. Then, at step 330, the true Doppler frequencies are transmitted to the target receiver.

5 Thereafter, at step 340, it is determined if the signal from the satellite is too weak to receive Ephemeris data. If not, the target receiver uses the true Doppler frequencies and tunes to those frequencies at step 350, and begins correlating at those frequencies at step 360. Otherwise, a terrestrial broadcast station sends Ephemeris data to the receiver at step 370 and the receiver calculates position using the Ephemeris data at step 380.

Almanac Data

10 At any given moment, only a portion of the satellites in a positioning system are currently usable. This is because as the satellites orbit the earth some fall below the horizon. When this happens, the signal from that satellite cannot be used, and is not expected to be used, by the receiver. Almanac data is used to inform a receiver exactly what satellites should currently be used. In one embodiment of the present invention, almanac data is calculated at a broadcast station and sent as part of the assistance signal so that the target receiver does not waste time looking for and trying to receive signals from a satellite that is below the horizon or otherwise
15 not desirable.
20

 This embodiment of the present invention is shown in Figure 4. At step 400, signals are transmitted from multiple satellites to earth. Then, at step 410, a broadcast station calculates

almanac data for a target receiver. Next, at step 420, the assistance signals, including the almanac data, are transmitted from a terrestrial broadcast station to the target receiver.

Thereafter, the target receiver locates the satellites indicated in the almanac data at step 430.

Finally, position information is obtained at step 440 by using the satellites indicated in the

5 almanac data.

Navigation Message

0
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195
200
205
210
215
220
225
230
235
240
245
250
255
260
265
270
275
280
285
290
295
300
305
310
315
320
325
330
335
340
345
350
355
360
365
370
375
380
385
390
395
400
405
410
415
420
425
430
435
440
445
450
455
460
465
470
475
480
485
490
495
500
505
510
515
520
525
530
535
540
545
550
555
560
565
570
575
580
585
590
595
600
605
610
615
620
625
630
635
640
645
650
655
660
665
670
675
680
685
690
695
700
705
710
715
720
725
730
735
740
745
750
755
760
765
770
775
780
785
790
795
800
805
810
815
820
825
830
835
840
845
850
855
860
865
870
875
880
885
890
895
900
905
910
915
920
925
930
935
940
945
950
955
960
965
970
975
980
985
990
995
1000
1005
1010
1015
1020
1025
1030
1035
1040
1045
1050
1055
1060
1065
1070
1075
1080
1085
1090
1095
1100
1105
1110
1115
1120
1125
1130
1135
1140
1145
1150
1155
1160
1165
1170
1175
1180
1185
1190
1195
1200
1205
1210
1215
1220
1225
1230
1235
1240
1245
1250
1255
1260
1265
1270
1275
1280
1285
1290
1295
1300
1305
1310
1315
1320
1325
1330
1335
1340
1345
1350
1355
1360
1365
1370
1375
1380
1385
1390
1395
1400
1405
1410
1415
1420
1425
1430
1435
1440
1445
1450
1455
1460
1465
1470
1475
1480
1485
1490
1495
1500
1505
1510
1515
1520
1525
1530
1535
1540
1545
1550
1555
1560
1565
1570
1575
1580
1585
1590
1595
1600
1605
1610
1615
1620
1625
1630
1635
1640
1645
1650
1655
1660
1665
1670
1675
1680
1685
1690
1695
1700
1705
1710
1715
1720
1725
1730
1735
1740
1745
1750
1755
1760
1765
1770
1775
1780
1785
1790
1795
1800
1805
1810
1815
1820
1825
1830
1835
1840
1845
1850
1855
1860
1865
1870
1875
1880
1885
1890
1895
1900
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
2100
2105
2110
2115
2120
2125
2130
2135
2140
2145
2150
2155
2160
2165
2170
2175
2180
2185
2190
2195
2200
2205
2210
2215
2220
2225
2230
2235
2240
2245
2250
2255
2260
2265
2270
2275
2280
2285
2290
2295
2300
2305
2310
2315
2320
2325
2330
2335
2340
2345
2350
2355
2360
2365
2370
2375
2380
2385
2390
2395
2400
2405
2410
2415
2420
2425
2430
2435
2440
2445
2450
2455
2460
2465
2470
2475
2480
2485
2490
2495
2500
2505
2510
2515
2520
2525
2530
2535
2540
2545
2550
2555
2560
2565
2570
2575
2580
2585
2590
2595
2600
2605
2610
2615
2620
2625
2630
2635
2640
2645
2650
2655
2660
2665
2670
2675
2680
2685
2690
2695
2700
2705
2710
2715
2720
2725
2730
2735
2740
2745
2750
2755
2760
2765
2770
2775
2780
2785
2790
2795
2800
2805
2810
2815
2820
2825
2830
2835
2840
2845
2850
2855
2860
2865
2870
2875
2880
2885
2890
2895
2900
2905
2910
2915
2920
2925
2930
2935
2940
2945
2950
2955
2960
2965
2970
2975
2980
2985
2990
2995
3000
3005
3010
3015
3020
3025
3030
3035
3040
3045
3050
3055
3060
3065
3070
3075
3080
3085
3090
3095
3100
3105
3110
3115
3120
3125
3130
3135
3140
3145
3150
3155
3160
3165
3170
3175
3180
3185
3190
3195
3200
3205
3210
3215
3220
3225
3230
3235
3240
3245
3250
3255
3260
3265
3270
3275
3280
3285
3290
3295
3300
3305
3310
3315
3320
3325
3330
3335
3340
3345
3350
3355
3360
3365
3370
3375
3380
3385
3390
3395
3400
3405
3410
3415
3420
3425
3430
3435
3440
3445
3450
3455
3460
3465
3470
3475
3480
3485
3490
3495
3500
3505
3510
3515
3520
3525
3530
3535
3540
3545
3550
3555
3560
3565
3570
3575
3580
3585
3590
3595
3600
3605
3610
3615
3620
3625
3630
3635
3640
3645
3650
3655
3660
3665
3670
3675
3680
3685
3690
3695
3700
3705
3710
3715
3720
3725
3730
3735
3740
3745
3750
3755
3760
3765
3770
3775
3780
3785
3790
3795
3800
3805
3810
3815
3820
3825
3830
3835
3840
3845
3850
3855
3860
3865
3870
3875
3880
3885
3890
3895
3900
3905
3910
3915
3920
3925
3930
3935
3940
3945
3950
3955
3960
3965
3970
3975
3980
3985
3990
3995
4000
4005
4010
4015
4020
4025
4030
4035
4040
4045
4050
4055
4060
4065
4070
4075
4080
4085
4090
4095
4100
4105
4110
4115
4120
4125
4130
4135
4140
4145
4150
4155
4160
4165
4170
4175
4180
4185
4190
4195
4200
4205
4210
4215
4220
4225
4230
4235
4240
4245
4250
4255
4260
4265
4270
4275
4280
4285
4290
4295
4300
4305
4310
4315
4320
4325
4330
4335
4340
4345
4350
4355
4360
4365
4370
4375
4380
4385
4390
4395
4400
4405
4410
4415
4420
4425
4430
4435
4440
4445
4450
4455
4460
4465
4470
4475
4480
4485
4490
4495
4500
4505
4510
4515
4520
4525
4530
4535
4540
4545
4550
4555
4560
4565
4570
4575
4580
4585
4590
4595
4600
4605
4610
4615
4620
4625
4630
4635
4640
4645
4650
4655
4660
4665
4670
4675
4680
4685
4690
4695
4700
4705
4710
4715
4720
4725
4730
4735
4740
4745
4750
4755
4760
4765
4770
4775
4780
4785
4790
4795
4800
4805
4810
4815
4820
4825
4830
4835
4840
4845
4850
4855
4860
4865
4870
4875
4880
4885
4890
4895
4900
4905
4910
4915
4920
4925
4930
4935
4940
4945
4950
4955
4960
4965
4970
4975
4980
4985
4990
4995
5000
5005
5010
5015
5020
5025
5030
5035
5040
5045
5050
5055
5060
5065
5070
5075
5080
5085
5090
5095
5100
5105
5110
5115
5120
5125
5130
5135
5140
5145
5150
5155
5160
5165
5170
5175
5180
5185
5190
5195
5200
5205
5210
5215
5220
5225
5230
5235
5240
5245
5250
5255
5260
5265
5270
5275
5280
5285
5290
5295
5300
5305
5310
5315
5320
5325
5330
5335
5340
5345
5350
5355
5360
5365
5370
5375
5380
5385
5390
5395
5400
5405
5410
5415
5420
5425
5430
5435
5440
5445
5450
5455
5460
5465
5470
5475
5480
5485
5490
5495
5500
5505
5510
5515
5520
5525
5530
5535
5540
5545
5550
5555
5560
5565
5570
5575
5580
5585
5590
5595
5600
5605
5610
5615
5620
5625
5630
5635
5640
5645
5650
5655
5660
5665
5670
5675
5680
5685
5690
5695
5700
5705
5710
5715
5720
5725
5730
5735
5740
5745
5750
5755
5760
5765
5770
5775
5780
5785
5790
5795
5800
5805
5810
5815
5820
5825
5830
5835
5840
5845
5850
5855
5860
5865
5870
5875
5880
5885
5890
5895
5900
5905
5910
5915
5920
5925
5930
5935
5940
5945
5950
5955
5960
5965
5970
5975
5980
5985
5990
5995
6000
6005
6010
6015
6020
6025
6030
6035
6040
6045
6050
6055
6060
6065
6070
6075
6080
6085
6090
6095
6100
6105
6110
6115
6120
6125
6130
6135
6140
6145
6150
6155
6160
6165
6170
6175
6180
6185
6190
6195
6200
6205
6210
6215
6220
6225
6230
6235
6240
6245
6250
6255
6260
6265
6270
6275
6280
6285
6290
6295
6300
6305
6310
6315
6320
6325
6330
6335
6340
6345
6350
6355
6360
6365
6370
6375
6380
6385
6390
6395
6400
6405
6410
6415
6420
6425
6430
6435
6440
6445
6450
6455
6460
6465
6470
6475
6480
6485
6490
6495
6500
6505
6510
6515
6520
6525
6530
6535
6540
6545
6550
6555
6560
6565
6570
6575
6580
6585
6590
6595
6600
6605
6610
6615
6620
6625
6630
6635
6640
6645
6650
6655
6660
6665
6670
6675
6680
6685
6690
6695
6700
6705
6710
6715
6720
6725
6730
6735
6740
6745
6750
6755
6760
6765
6770
6775
6780
6785
6790
6795
6800
6805
6810
6815
6820
6825
6830
6835
6840
6845
6850
6855
6860
6865
6870
6875
6880
6885
6890
6895
6900
6905
6910
6915
6920
6925
6930
6935
6940
6945
6950
6955
6960
6965
6970
6975
6980
6985
6990
6995
7000
7005
7010
7015
7020
7025
7030
7035
7040
7045
7050
7055
7060
7065
7070
7075
7080
7085
7090
7095
7100
7105
7110
7115
7120
7125
7130
7135
7140
7145
7150
7155
7160
7165
7170
7175
7180
7185
7190
7195
7200
7205
7210
7215
7220
7225
7230
7235
7240
7245
7250
7255
7260
7265
7270
7275
7280
7285
7290
7295
7300
7305
7310
7315
7320
7325
7330
7335
7340
7345
7350
7355
7360
7365
7370
7375
7380
7385
7390
7395
7400
7405
7410
7415
7420
7425
7430
7435
7440
7445
7450
7455
7460
7465
7470
7475
7480
7485
7490
7495
7500
7505
7510
7515
7520
7525
7530
7535
7540
7545
7550
7555
7560
7565
7570
7575
7580
7585
7590
7595
7600
7605
7610
7615
7620
7625
7630
7635
7640
7645
7650
7655
7660
7665
7670
7675
7680
7685
7690
7695
7700
7705
7710
7715
7720
7725
7730
7735
7740
7745
7750
7755
7760
7765
7770
7775
7780
7785
7790
7795
7800
7805
7810
7815
7820
7825
7830
7835
7840
7845
7850
7855
7860
7865
7870
7875
7880
7885
7890
7895
7900
7905
7910
7915
7920
7925
7930
7935
7940
7945
7950
7955
7960
7965
7970
7975
7980
7985
7990
7995
8000
8005
8010
8015
8020
8025
8030
8035
8040
8045
8050
8055
8060
8065
8070
8075
8080
8085
8090
8095
8100
8105
8110
8115
8120
8125
8130
8135
8140
8145
8150
8155
8160
8165
8170
8175
8180
8185
8190
8195
8200
8205
8210
8215
8220
8225
8230
8235
8240
8245
8250
8255
8260
8265
8270
8275
8280
8285
8290
8295
8300
8305
8310
8315
8320
8325
8330
8335
8340
8345
8350
8355
8360
8365
8370
8375
8380
8385
8390
8395
8400
8405
8410
8415
8420
8425
8430
8435
8440
8445
8450
8455
8460
8465
8470
8475
8480
8485
8490
8495
8500
8505
8510
8515
8520
8525
8530
8535
8540
8545
8550
8555
8560
8565
8570
8575
8580
8585
8590
8595
8600
8605
8610
8615
8620
8625
8630
8635
8640
8645
8650
8655
8660
8665
8670
8675
8680
8685
8690
8695
8700
8705
8710
8715
8720
8725
8730
8735
8740
8745
8750
8755
8760
8765
8770
8775
8780
8785
8790
8795
8800
8805
8810
8815
8820
8825
8830
8835
8840
8845
8850
8855
8860
8865
8870
8875
8880
8885
8890
8895
8900
8905
8910
8915
8920
8925
8930
8935
8940
8945
8950
8955
8960
8965
8970
8975
8980
8985
8990
8995
9000
9005
9010
9015
9020
9025
9030
9035
9040
9045
9050
9055
9060
9065
9070
9075
9080
9085
9090
9095
9100
9105
9110
9115
9120
9125
9130
9135
9140
9145
9150
9155
9160
9165
9170
9175
9180
9185
9190
9195
9200
9205
9210
9215
9220
9225
9230
9235
9240
9245
9250
9255
9260
9265
9270
9275
9280
9285
9290
9295
9300
9305
9310
9315
9320
9325
9330
9335
9340
9345
9350
9355
9360
9365
9370
9375
9380
9385
9390
9395
9400
9405
9410
9415
9420
9425
9430
9435
9440
9445
9450
9455
9460
9465
9470
9475
9480
9485
9490
9495
9500
9505
9510
9515
9520
9525
9530
9535
9540
9545
9550
9555
9560
9565
9570
9575
9580
9585
9590
9595
9600
9605
9610
9615
9620
9625
9630
9635
9640
9645
9650
9655
9660
9665
9670
9675
9680
9685
9690
9695
9700
9705
9710
9715
9720
9725
9730
9735
9740
9745
9750
9755
9760
9765
9770
9775
9780
9785
9790
9795
9800
9805
9810
9815
9820
9825
9830
9835
9840
9845
9850
9855
9860
9865
9870
9875
9880
9885
9890
9895
9900
9905
9910
9915
9920
9925
9930
9935
9940
9945
9950
9955
9960
9965
9970
9975
9980
9985
9990
9995
10000
10005
10010
10015
10020
10025
10030
10035
10040
10045
10050
10055
10060
10065
10070
10075
10080
10085
10090
10095
10100
10105
10110
10115
10120
10125
10130
10135
10140
10145
10150
10155
10160
10165
10170
10175
10180
10185
10190
10195
10200
10205
10210
10215
10220
10225

such as at location 501B and 501E. The noninverted strings represent a navigation message bit with a value of 1 while the inverted strings represent a 0 navigation message bit.

For typical outdoor operation of a receiver, this system works adequately because the receiver is able to capture the correlation data relatively easily. At each navigation data transition from one polarity to another (e.g. a 1 bit to a 0 bit or vice-versa) the correlator of a receiver loses its correlation. The receiver assumes that an inversion has occurred, notes the navigation message bit value, and then attempts to lock onto the inverted correlation data string, usually successfully before the next navigation message bit transition.

This does not work as well in indoor uses. There, the receiver may need to correlate for a much longer period of time to achieve an adequate signal to noise ratio. The present invention solves this problem by sending the navigation message bits to the receiver via the terrestrial broadcast station. In this manner, the receiver can predict the inversions and look for the inverted string without ever losing the correlation on the satellite signal. When the transition of the correlation code string is about to occur based on the received navigation message data from the terrestrial broadcast station, the receiver can invert the signal so that the correlator maintains its lock on the correlation code.

The operation of this system is illustrated in the flow diagram of Figure 6. At step 600, the satellite transmits the correlation code signal string to Earth, inverting it periodically to represent navigation message data bits. The target receiver receives the signal from space and the navigation message data from a terrestrial broadcast station at step 610. At step 620, the

receiver correlates the data from the satellite. At decision block 630, the receiver uses the navigation message data from the terrestrial broadcast station to determine if an inversion of the navigation signal is about to occur. If no, the receiver continues correlating the signal at step 620. If yes, the receiver inverts the incoming correlation signal at the appropriate transition time at step 640 so that there is no loss of correlation due to data inversion. The system continues correlating at step 620.

The broadcast station should be relatively close, less than 100 miles away for instance, so that they receive essentially the same signal from the satellite. Using the string sent from the broadcast station, the target receiver is able to know when the inversions will occur, look for the inversions, and hence, the navigation message, while at the same time continuing to correlate on the weak signal.

Assistance Signal Architecture

An example of an architecture that may be used to transmit assistance signals is shown in Figure 7. A positioning system antenna 700 receives a satellite signal and transmits it to a positioning system radio frequency (RF) part 710. RF part 710 might include, for instance, conventional means for amplifying the received signal (amplifier), filtering it, and down-converting it to an appropriate intermediate frequency. The amplified and down-converted signal is then applied to a conventional analog to digital converter 720. The output of the converter 720, which represents the digital amplitude samples of the down-converted positioning system signal is stored in a memory 730 for subsequent signal processing.

When appropriate, the positioning system signal stored in memory 730 is transmitted to receiver logic unit 735. A broadcast station 740 having its own antenna 750 also receives signals from satellites and transmits assistance signal 760 to receiver logic unit 735 as well. Receiver logic unit 735 is configured to respond to multiple types of assistance data. In the case where the navigation message is sent in the assistance signal, receiver logic unit 735 might perform a re-inversion of the data when the navigation message inverts, for instance by correlating with a matched filter, a correlater, a Fast Fourier Transform (FFT) unit, or other suitable device.

Receiver logic unit 735 may be a component of a computing device, such as a personal digital assistant, cellular phone, or general purpose computer. Assistance signal 760 may be a provided by a wire, a computer network such as the Internet, or it may be provided wirelessly, such as via a cellular telephone network, wireless data network, a secondary carrier on a transmitter in the commercial broadcast service (TV or AM/FM radio) or by another equivalent means. Memory unit 730 may be used to store data that is not completely transient in nature (i.e., Ephemeris data) and transmit it later to the receiver logic unit 735 when needed.

Ghost Satellite

Satellites use unique codes to reduce the likelihood of misidentification of a satellite. These codes are known as “Gold Codes”. Gold codes are series of identification signals sent by the satellites that have unique properties. Gold codes are identification strings approximately one

thousand bits long. Of the possible one thousand bit strings, around sixty are chosen. Each of the chosen Gold codes is orthogonal.

The chance that a receiver that is correlating to a certain signal could correlate to the signal from another satellite is low but is possible. This condition can arise when the potentially interfering signal becomes significantly stronger than the desired signal. This can occur when the signal from the desired satellite is attenuated by some physical interference but the signal from the undesired satellite has a clearer path to the receiver (often via a reflection path). The undesired signal is considered to be a "ghost" signal and its source is a "ghost" satellite. The orthogonality of the Gold Codes usually means that if a correlator is locking in on an identification string and a ghost signal interferes, another satellite's identification string will not be obtained. Orthogonality, however, is only effective at certain levels. Namely, if the interfering signal becomes much stronger than the desired signal, then the correlator may read that signal as being the desired signal (ghost satellite effect).

Take, for instance, the user of a receiver that is blocked by a number of trees. If the desired code transmission is blocked by the trees and the undesired code transmission has a direct path to the receiver, ghost satellite error may occur. For prior art receivers, this problem is usually solved by limiting the strength at which valid codes will be read. The ghost signal is usually below a certain amplitude. By amplitude filtering below a certain signal strength, those unwanted signals are eliminated and only strong desired signals are obtained.

This can work for outdoor use of receivers where strong signals are available. For indoor receivers used in embodiments of the present invention, however, such a scheme is ineffective. This is because indoors the desired signal itself may be so weak that it is below the cutoff range for ghost signals. If the low amplitude signals are no longer filtered out, the chance of ghost satellite error returns.

The present invention solves this problem by having a dual path for correlation. In one path a conventional correlator is used to look for energy from correlation of a desired signal. If it finds any signal, it is presumed to be a ghost signal. The first path then inverts this detected signal and provides it to a second correlator path where it cancels out the potential ghost signal and leaves only the potential of the desired signal. If any appreciable signal is obtained at the second correlator path, that signal can be presumed to be the desired signal.

In one embodiment of the present invention, the effect of the undesired satellite can be computed given knowledge of the code phases and the Doppler frequencies and thus be subtracted from the data sample stored in memory unit 730. In practice, this process is iterative; that is, the pseudoranges and signal strengths are estimated and these are subtracted from the contents of the memory unit 730. The subtracting values may be extracted from a table computed in advance and recalculated with respect to an amplitude and phase of the acquired undesired signal.

Embodiment of a Positioning System

One embodiment of a positioning system according to the present invention is illustrated in Figure 8. An assistance receiver 812 is coupled to an antenna 811. The assistance data receiver 812 provides navigation bits, Doppler frequencies, time synchronization, ephemeris data, base station coordinates for 1 ms ambiguity resolution, and pseudo-range differential corrections to a local broadcast network that may be wired, wireless, cellular, or network or internet based.

The SPS receiver in the embodiment of Figure 8 comprises an antenna 801 coupled to a processing block 802. The output of processing block 802 is coupled to A/D converter 803 and memory 804 to difference node 805. The output of node 805 is coupled to filter block 806 along with data from the assistance receiver 812. Filter block 806 is coupled to accumulation block 808 and through iteration block 809 to ambiguity resolution block 810.

The output of memory 804 is also coupled to correlation and tracking block 813 which provides output to difference node 805 and to navigation data decoding block 814. The output of block 814 is coupled to memory 816 and to position computation block 815. Ephemeris data and differential corrections data from the assistance receiver 812 is also coupled to position computation block 815 as is memory 816. The position computation block exchanges data with resolution block 810.

In operation, the received satellite signal from antenna 801 is inputted to an RD processing section 802 which includes conventional means for amplifying the received signal (amplifier), filtering it, and down-converting it to an appropriate intermediate frequency (IF). The amplified and down-converted signal is then applied to a conventional analog to digital (A/D) converter 803. The output of the A/D converter, which represents the digital amplitude samples of the down-converted signal is stored in a memory 804 for subsequent signal processing.

For low SNR processing of signals, it is desirable to eliminate the effects of cross-correlations from satellites other than the satellite being acquired or tracked. The peak cross-correlation coefficient between all conventional GPS C/A Gold Codes is 65/1023. Additionally, frequency offsets may result in this being even higher. To minimize the “ghost satellite” effect, a numerical representation of the undesired signal may be subtracted from the digital samples stored in memory at difference block 805 in Figure 8. The value to be subtracted is generated by signal correlation and tracking block 813.

The output of difference block 805 is applied at filter block 806. Filter block 806 may be comprised of primary and secondary matched filters, or it may be a single structure such as an FFT, or other convolution or correlation device. The output of filter block 806 is applied to non-coherent accumulator 808 which performs a non-coherent detection and accumulation. The non-coherent detection computes some function of the modulus of the output of block 806. The two functions are the modulus and the modulus squared in one embodiment. Typical coherent

integration times are on the order of 100 mSec. Non-coherent accumulation would typically be performed on data corresponding to a one second interval of the received signal.

The output of the cross-coherent accumulator is applied to block 809 that iteratively estimates the sub-millisecond pseudorange to the satellite in question. The pseudorange is ambiguous at the one mSec level. It is the function of ambiguity resolution block 810 to resolve the millisecond ambiguity in the pseudorange in a conventional manner. Block 810 takes as its inputs distances to satellites from a position computation performed at computation block 815.

Assistance data from the aiding receiver 812 communicates the navigation message bits, i.e., telemetry data, Doppler information, base station coordinates for 1 ms ambiguity resolution, PRN numbers and time synchronization information to the filter matched to the C/A and navigation message bits at filter block 806. The aiding SPS receiver also communicates ephemerides and differential corrections (if implemented) to the position computation block 815. Ephemerides may be stored in memory 816 for later use if desired.

The output memory 804 is also connected to the satellite correlation and tracking module 813. In one embodiment, block 813 is a standard SPS correlator. It is aided by the C/A code pseudorange estimates from block 809. The satellite correlation and tracking module 813 is used to derive navigation data from the data stored in memory 804 when the received satellite signal strength is high. In traditional applications, ghost signals are avoided by setting a limit range for a signal to be detected. In obstructed situations, such a limit range may prevent the detection of

the actual signal. To avoid this, the present invention contemplates using the conventional correlator path to generate any ghost signal correlation and remove it at the difference block 805.

When the signal is weak, such as in an obstructed area (a low SNR condition), Ephemeris data may be stored in memory 816 wherever and whenever it is found by block 813 and block 814 from the SPS receiver. Then it may be used in later conditions where the signal is too weak to allow Ephemeris data to be collected by the SPS receiver. Thus, operation of the aided SPS receiver may continue for a time (typically up to several hours) until the Ephemeris data goes out of date. (Differential corrections may also be stored but these go out of date much more quickly).

The position computation block 815 takes as its inputs Ephemeris data derived from the navigation message decoded in block 814 (and optionally stored in memory 816), or data from the aiding SPS receiver 812 or the stored message in memory 816. Additionally it may use differential corrections from aiding SPS receiver 812 and pseudoranges from the pseudorange ambiguity resolution module 810.

Three points merit special mention at this point. First, the signal correlation and tracking module 813 does not work independently of the filter matched to the C/A code and navigation message bits (block 806). This is because the SNR of the received signal may be inadequate to allow the received signal to be tracked. By operating on the stored data, the causality

requirement of the tracking loops is eliminated. Second, this technique does not compute the full cross-correlation function between the data and the locally generated signals. This is because the correlation coefficients are not computed for the uninteresting lags.

5 Finally, the data memory size can be reduced to the size necessary to store an amount of data that corresponds to the coherent integration period. If, after processing the first data set it is determined that additional data is needed, additional data may be required and stored in memory 804, processed, and the processed results combined with the results of the first processing results for improved accuracy or strength of a statistical test. Similarly, any number of subsequent
10 samples may be acquired, processed, and incorporated into the pseudorange measurements and position computation.

Filter Block

15 In one or more embodiments of the present invention, a filter block, such as block 806 of Figure 8, is used. In one embodiment, filter block 806 is broken into a primary and a secondary matched filter. In operation, the input to the primary matched filter is matched to the product of the C/A code, the telemetry data (navigation bits from the carrier phase reversal signal) and the carrier frequency of the desired satellite signal. This technique differs from techniques that use a
20 filter matched to only the product of the C/A code and a carrier frequency. There are two

important differences: First, the technique of using a filter matched to the product which includes telemetry data has the capability to out perform techniques which do not use the telemetry data. This is because the use of the telemetry data allows Longer Coherent Integration of the received signal and subsequently it permits improved post-correlation SNR. Second, the technique of using a filter matched to the product which includes telemetry data differs mathematically from FFT-based techniques which perform convolutions or correlations on the product of the pseudo random noise (PRN) (the C/A code) and the carrier; these FFT-based convolutions or correlations employ circular convolution which implicitly assumes periodic extensions of the PRN code with the same telemetry bit sign.

The output of the primary filter may be viewed as complex correlation coefficients between the data input to the matched filter. This output is applied to a second matched filter. If T denotes the sample period of the primary filter, the ideal matched secondary filter is given by Bracewell's triangle function, the zeros of which correspond to one C/A code "chip" (define), convolved with the baseband equivalent of the composite of filters in the receiver, sampled at an interval T . The purpose of this secondary filter is to improve SNR by the complex correlation coefficients prior to non-coherent detection and subsequent accumulation. Loosely, the secondary filter uses information in samples adjacent to the peak correlation coefficient to improve the SNR. More precisely, to maximize SNR, the complex correlation coefficients are applied sequentially to the filter which has as its impulse response the time-reverse, complex conjugate of the above described filter. Practically, this filter may be approximated by a binary approximation to the ideal response. Since both of these operations are linear, they could, of

course, be combined in a single filter. However, to do so would result in a more complex implementation.

In practice, one embodiment of the ghost satellite cancellation may use primary and secondary matched filters. In operation, the process is iterative; that is, the pseudoranges and signal strengths are estimated and these are subtracted from the contents of memory. This cancellation of the effect of undesired satellites may need not be implemented by subtracting from data primarily stored in the memory samples. More generally, the compensation may be done at any stage of data processing before the nonlinear detection operation, i.e., squaring or taking the modulus. In practice, there are computational advantages to performing this subtraction on the output of the filter, matched to the output of the filter, matched to the C/A code and navigation bits or the secondary matched filter. The subtracting values can be extracted from a table computed in advance and recalculated with respect to an amplitude and phase of the acquired undesired signal.

Thus, a method and apparatus for reducing interference in a positioning system is described in conjunction with one or more specific embodiments. The invention is defined by the claims and their full scope of equivalents.